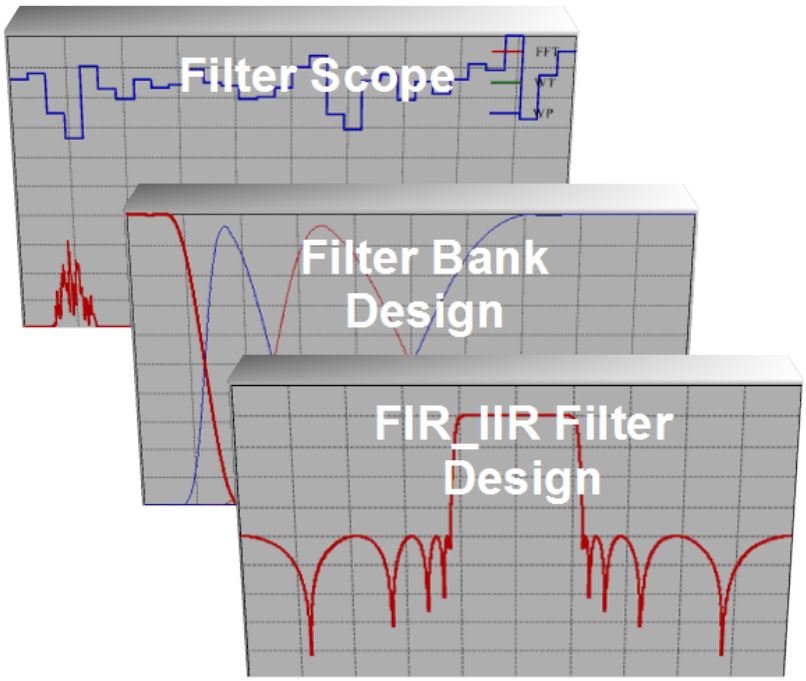
FIR IIR Filter Design

User Manual



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Thank you for buying Innosolve product. We sincerely hope that this product will provide useful assistance in the design of digital filters, and in better understanding their operation. Innosolve Ltd. is committed to quality, constantly improving its products based on customer feedback.
In the field of digital signal processing, more than 20 years of solid professional background is a guarantee of quality.

1./ General introduction of FIR IIR Filter Design software module

FIR IIR Filter Design software is intended to design IIR and FIR digital filters in a simple and fast way, in a user friendly environment. The filter type can be LP, HP, BP, and BS. IIR filters can be designed in an order of 1 – 20 by Bessel, Butterworth, Chebyshev I and Chebyshev II methods, whereas FIR filters by Rectangular, Bartlett, Hahn, Hamming, Blackman and Kaiser method taps of 2 – 9999.

This program supports designing of LP, HP, BP and BS filters with ParksMcClellan algorithm (which can be find under the name of Remez) up to 1000 taps as well as so called Combined filters in the range of 2 – 10 bands.

Behavior of filters can be studied on six different graphs. These are the amplitude – frequency, phase – frequency, group delay – frequency, impulse response, step response graphs and the pole-zero diagram.

FIR IIR Filter Design displays filter coefficients in text boxes, from which the coefficients can be copied into other documents, even into source code with the well known copy / paste method.

The software provides several opportunities for filter documentation: saving filter into file, printing graphs and coefficients, copying any graphs.

In addition **FIR IIR Filter Design** provides the opportunity to compute filter graphs from user defined coefficients. With this feature we can determine filter graphs of averaging function, filters designed by another software, wavelet filters, etc.

Environmental conditions

Operation system	MS Windows 7, 8, 10 32 / 64 bit
Display resolution [pixel]	Minimum 1024 x 768
RAM memory	Minimum 1 GByte
Processor	>=2 cores

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2./ Functions

2.1/ Main

Filter type and parameters can be determined in the *Main* window. Parameter fields are displayed according to the filter type chosen. Parameter values can be modified by the up / down arrows or by typing a value directly into the parameter field.

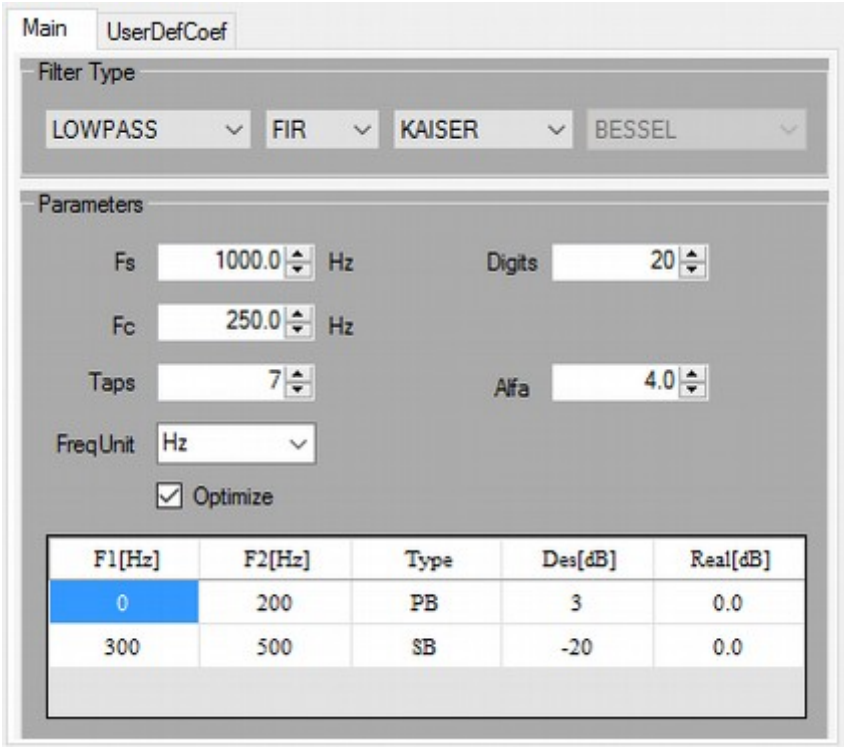

Fig. 1. Main window

2.1.1/ Filter Type

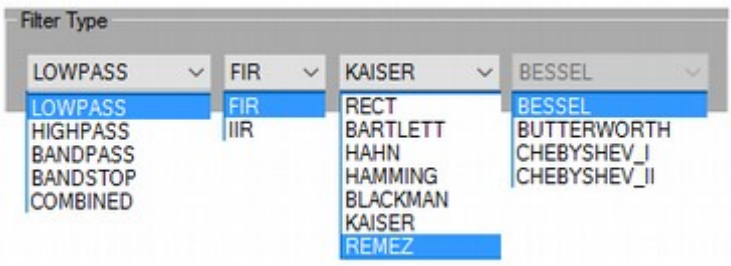

Fig. 2. Setting filter type

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Filter type can be selected here. Types can be selected according to frequency response (LP, HP, BP, BS), impulse response (IIR, FIR) and the method of the filter design.

2.1.2/ Parameters

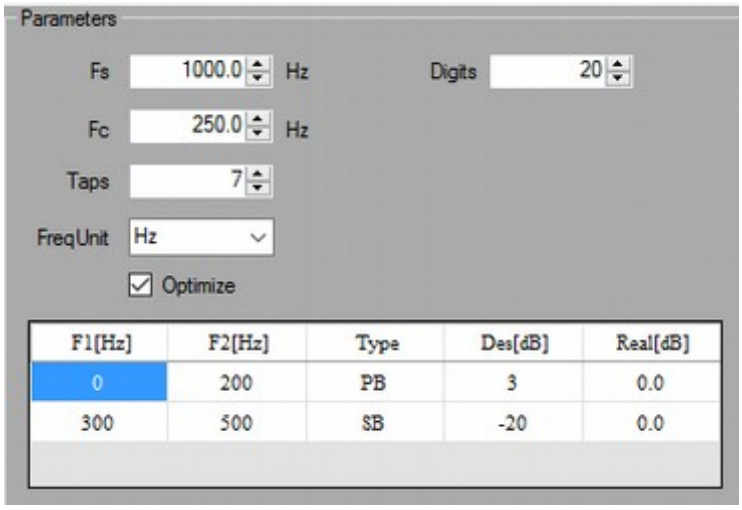

Fig. 3. Setting Parameters

Filter parameters can be set here: sample rate (*Fs*), corner frequency (*Fc*), center frequency (*Fc*) and bandwidth (*B*) at BP and BS, filter order (*Order* or *Taps*), attenuation parameters (*Ap, As, Alfa*).
The program displays those parameters only which are relevant to the chosen filter type, other parameters are hidden.
By modifying the *Digits* parameter we can examine how the word length affects filter response.

In the table can be seen in the picture above, we can define the desired passband and stopband parameters of the filter we want to design. The program displays them on FreqResp graph.
Meaning of the parameters:

F1	Beginning of band
F2	End of band
PB	Passband
SB	Stopband
Des[dB]	Desired passband ripple or stopband attenuation
Real[dB]	Measured passband ripple or stopband attenuation

The program handles the passband ripple as +/-.
At Remez/Combined filters the program designs the filter on parameters specified in the table.

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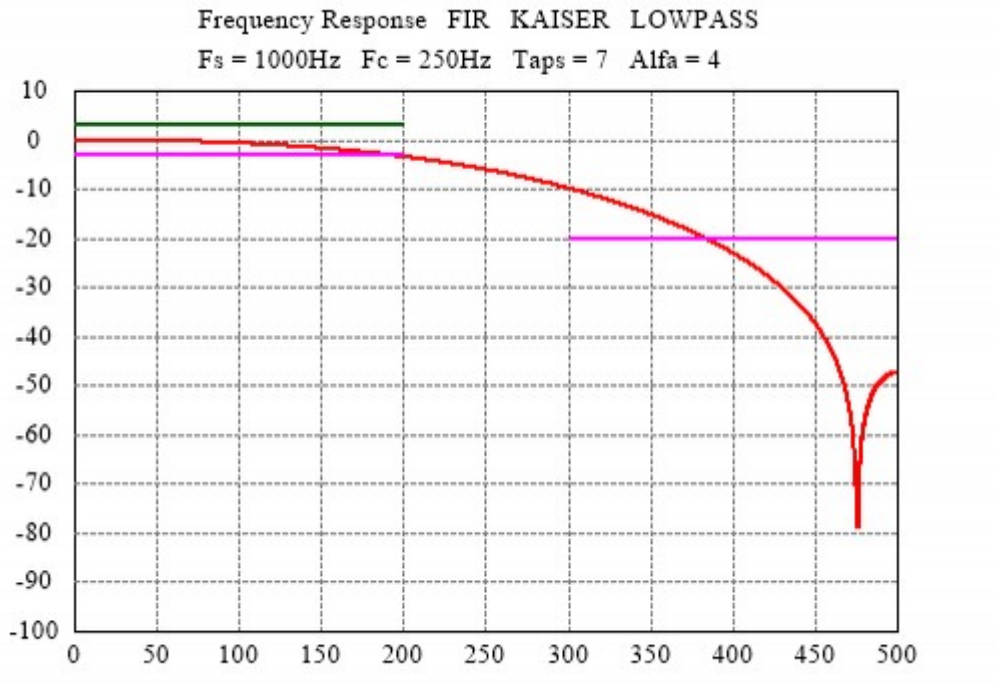

Fig.4. Display desired curves

Magenta: Parameter is not fulfilled
Zöld: Parameter is fulfilled

2.2/ Controls

Fig. 5. Control buttons

Program counts filter graphs and coefficients by clicking on the ***Realize*** button. We can exit from the program by clicking on the ***Exit*** button.

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2.3/ UserDefCoef

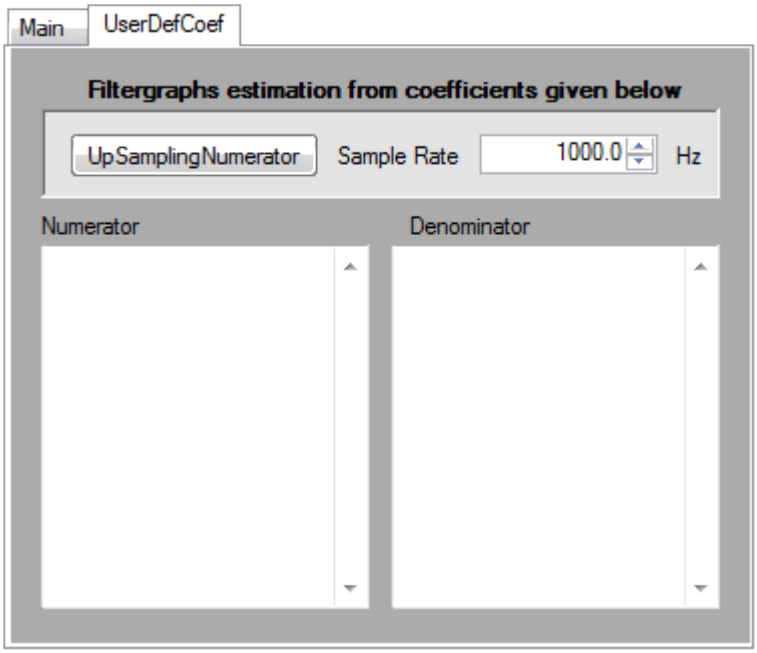

Fig. 6. User defined coefficient window

The program gives possibility to the user to type filter coefficients into Numerator and Denominator text boxes. Then clicking on the Realize button (see previous chapter) **FIR IIR Filter Design** counts filter graphs from the user defined filter coefficients. Some applications of this function: determining frequency graphs of moving average, mother wavelet LP, HP filters, etc.

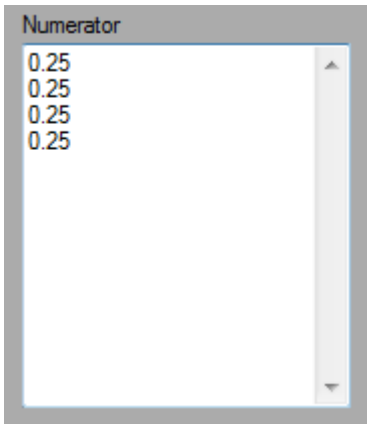

Fig. 7. Coefficients of four samples averager

In order to test a four-sample moving average, type 0.25 four times into the Numerator box as it is seen on Fig. 6. Set SampleRate to the desired value, then clicking on the Realize button the program counts filter graphs.

Clicking on the UpSampling button zeros will be inserted between samples. Every clicking will double the sample rate. Important to know, that the UpSampling effects Numerator box. Pushing this button writes 1 to Denominator box.

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In case of IIR filter the program accepts Numerator and Denominator coefficients with or without Stages. When using filters with higher order it is recommended to divide coefficients into Stages in order to avoid “numeric word length” distortion (see Fig. 7).

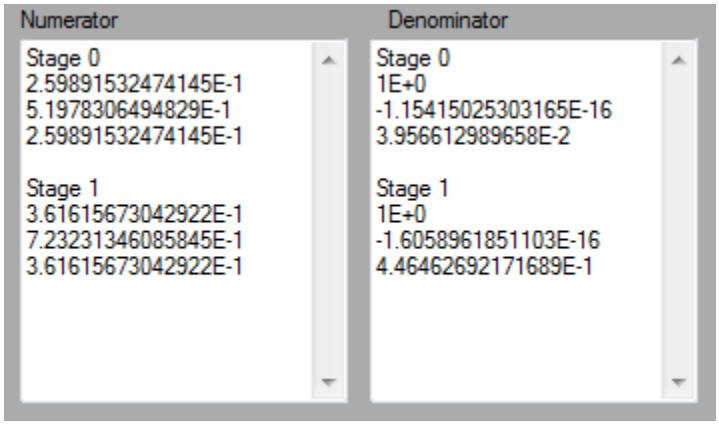

Fig. 8. Entering filter coefficients divided into stages

Meaning of Numerator coefficients in Fig. 7.

Stage 0
a[0] = 2.59891532474145E-1
a[1] = 5.1978306494829E-1
a[2] = 2.59891532474145E-1

Stage 1
a[0] = 3.61615673042922E-1
a[1] = 7.23231346085845E-1
a[2] = 3.61615673042922E-1

Place of the Numerator coefficients in the polynomial:

$$...a[2] * z^{-2} + a[1] * z^{-1} + a[0]$$

Meaning of Denominator coefficients in Fig. 7.

Stage 0
b[0] = 1E+0
b[1] = -1.15415025303165E-16
b[2] = 3.956612989658E-2

Stage 1
b[0] = 1E+0
b[1] = -1.6058961851103E-16
b[2] = 4.46462692171689E-1

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Place of the Denominator coefficients in the polynomial:

$$...b[2] * z^{-2} + b[1] * z^{-1} + b[0]$$

In case of FIR filters there is no feedback, hence FIR filters are always stable, there is no need to divide into stages.

Important notice! The program uses '.' as decimal point.

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3./ Filter Graphs

3.1/ Freq Resp

Amplitude – frequency graph with frequency on horizontal and amplitude on vertical axis. Both axis can be switched to linear and log mode.

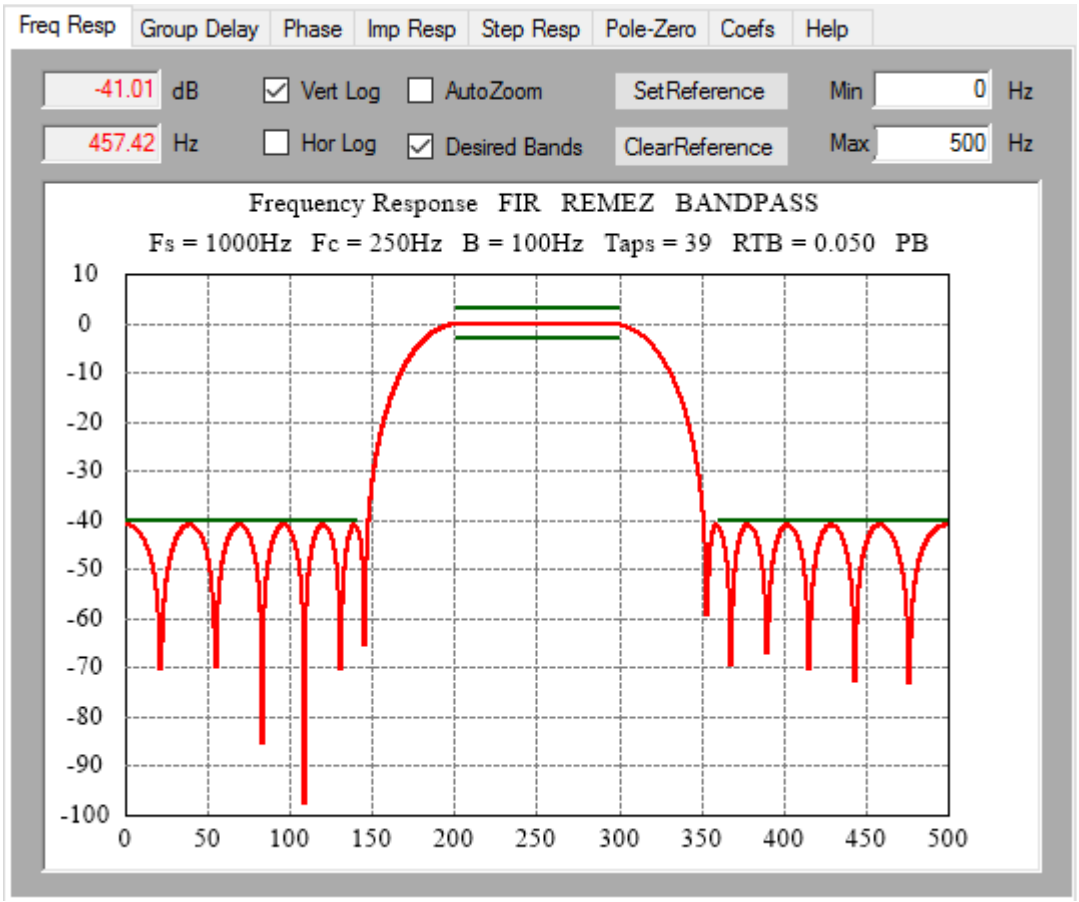

Fig. 9. Amplitude – frequency graph

By moving the cursor above graph the program displays the frequency and amplitude value according to the cursor position.
In order to study a certain part of the graph, the range of the horizontal axis can be changed by modifying the value of Min and Max fields.

This window gives possibility to fix a curve as reference by clicking on the SetReference button. This function is very helpful when comparing different curves to each other.
A Copy menu pops up by right-clicking on the graph. By left-Clicking on the Copy the picture will be copied to clipboard. Afterwards the picture (graph) can be copied into our document.

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3.2/ Group Delay

Group delay time is the derivative of phase – frequency curve. For engineers this parameter is more meaningful than the phase.
The group delay is constant in case of FIR filters and equals to Taps / 2, the half of the number of filter coefficients.
In case of IIR filters the situation is different, because the phase – frequency curve is not linear, so the group delay will not be linear either. At Bessel filters which are called as minimal phase filters, group delay time remains almost constant in the passband.
When moving the cursor above the graph the program displays the frequency and group delay value according to the cursor position.

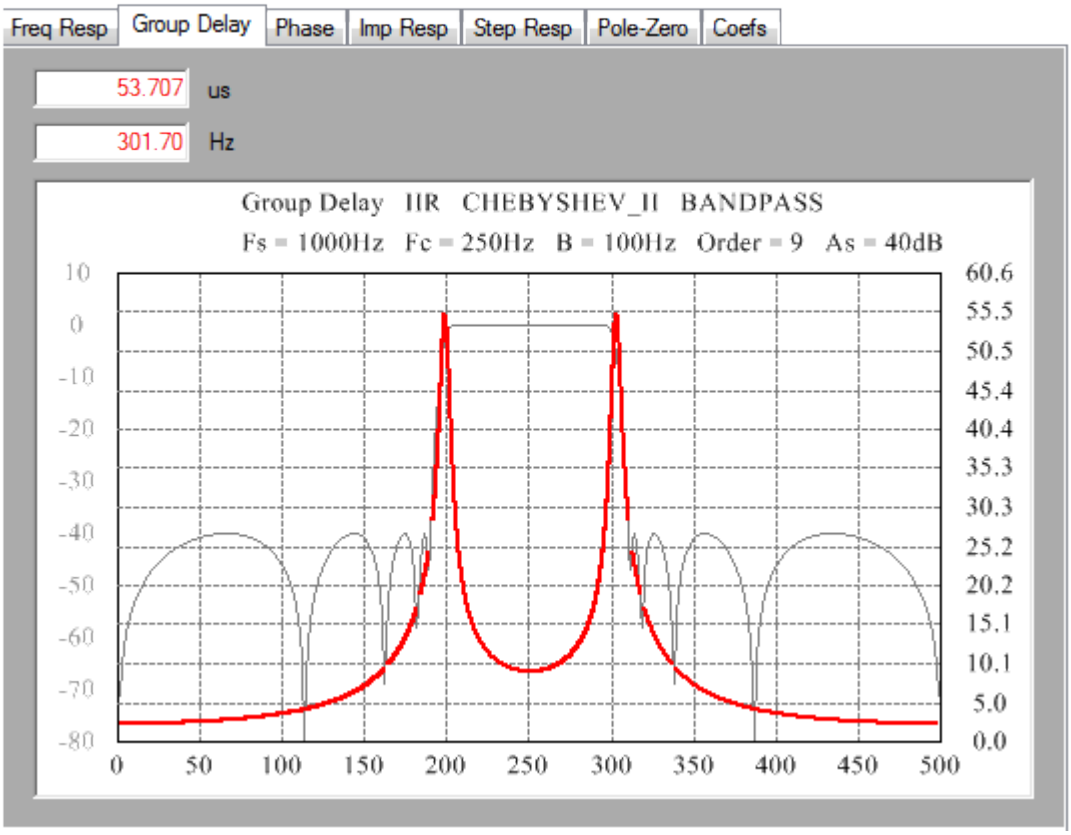

Fig. 9. Group delay – frequency graph

The amplitude – frequency curve is displayed with grey colour in the same graph so that two curves shall be referenced to each other.
A Copy menu pops up by right-clicking on the graph. By left-Clicking on the Copy the picture will be copied to clipboard. Afterwards the picture (graph) can be copied into our document.

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3.3/ Phase

Phase – frequency graph displayed in radian or degree.
By moving the cursor above the graph the program displays the frequency and phase value according to the cursor position.
The amplitude – frequency curve is displayed with grey colour in the same graph so that two curves shall be referenced to each other.
A Copy menu pops up by right-clicking on the graph. By left-Clicking on the Copy the picture will be copied to clipboard. Afterwards the picture (graph) can be copied into our document.

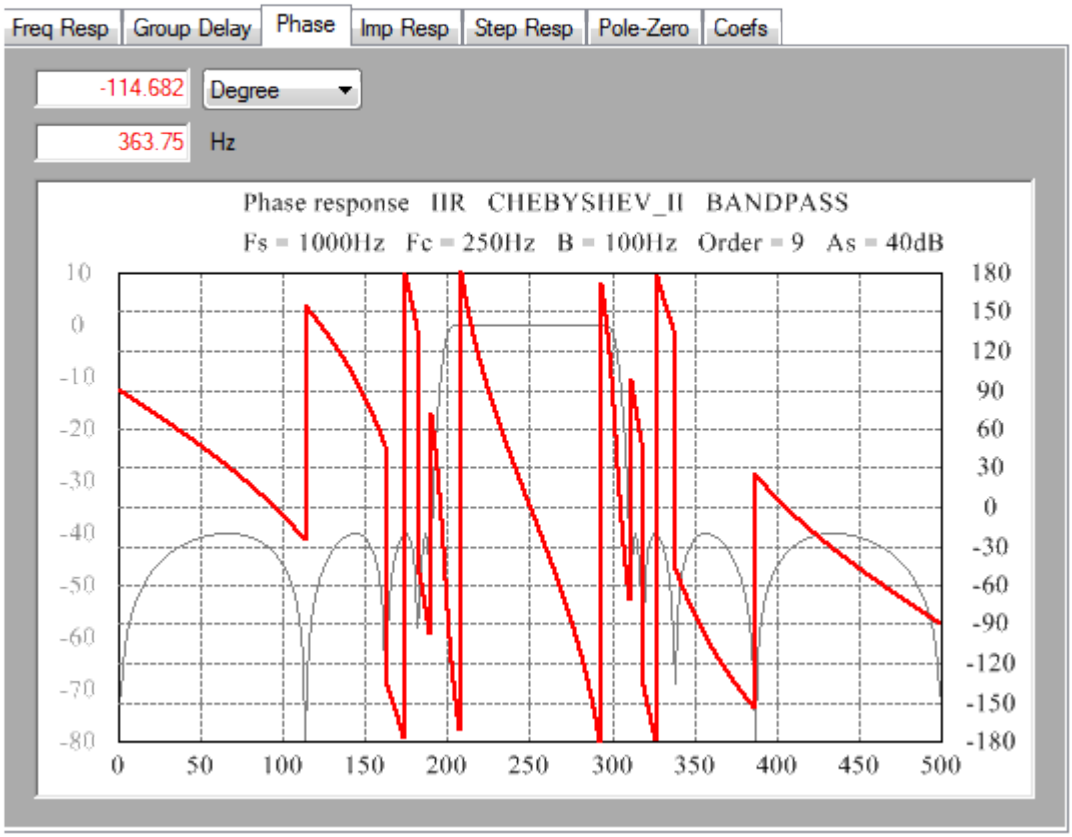

Fig. 10. Phase – frequency graph

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3.4/ Imp Resp

Impulse response graph. A special stream is given to the input of the filter. The values of this stream are zeros except for one value, which is 1. The filter response is called impulse response for this input.

By moving the cursor above the graph the program displays the time and magnitude value according to the cursor position.
A Copy menu pops up by right-clicking on the graph. By left-Clicking on the Copy the picture will be copied to clipboard. Afterwards the picture (graph) can be copied into our document.

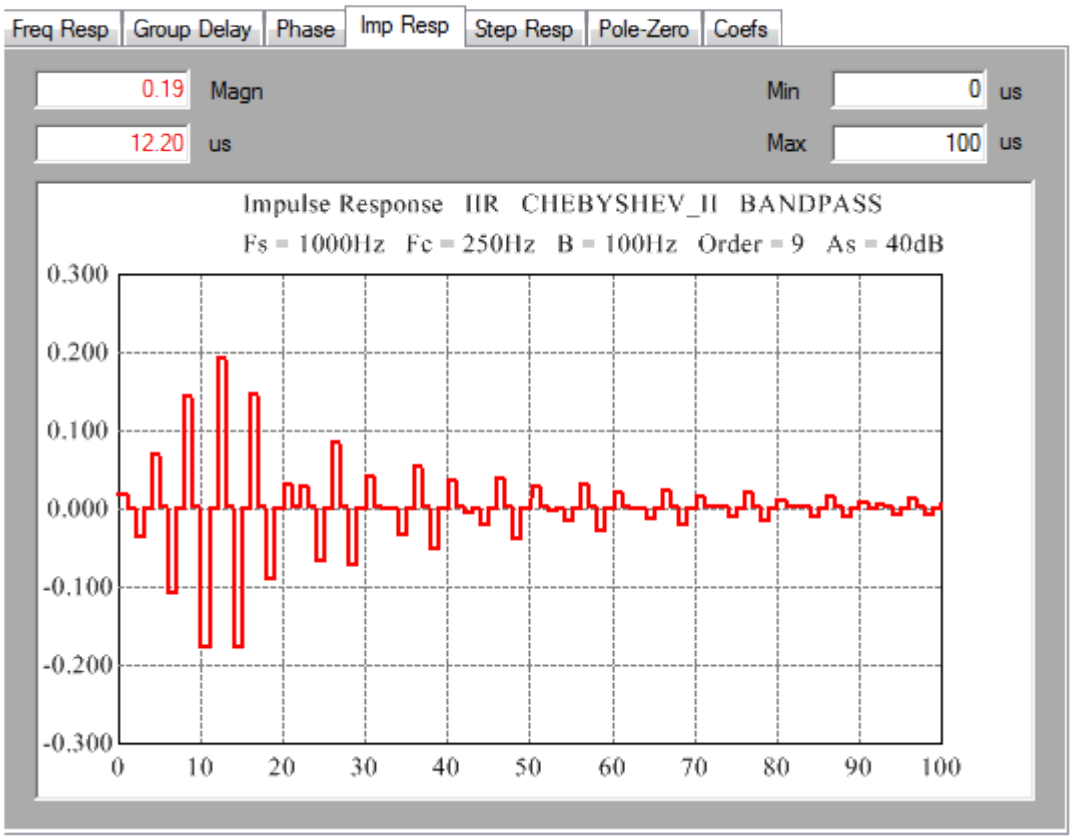

Fig. 11. Impulse response

The range of the time axis can be scaled by modifying Min and Max.

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3.5/ Step Resp

Step response graph. A special stream is given to the input of the filter. All values of this stream are 1. The filter response is called step response for this input.

By moving the cursor above the graph, the program displays the time and magnitude value according to the cursor position.
A Copy menu pops up by right-clicking on the graph. By left-Clicking on the Copy the picture will be copied to clipboard. Afterwards the picture (graph) can be copied into our document.

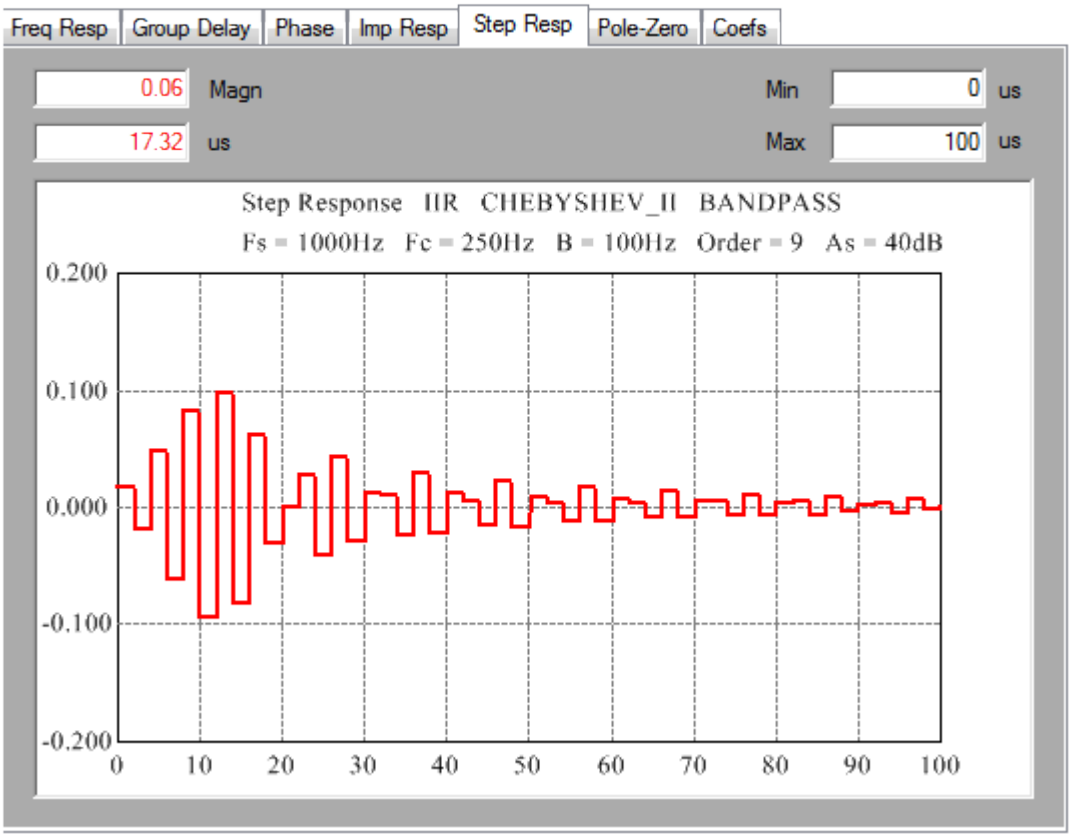

Fig. 12. Step response

The range of the time axis can be scaled by modifying Min and Max.

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3.6/ Pole Zero

The program displays poles and zeros of filter polynomials. Ellipsoidal form is used instead of circle because of the automatic scaling. Zeros are marked by blue circles, poles by red crosses.

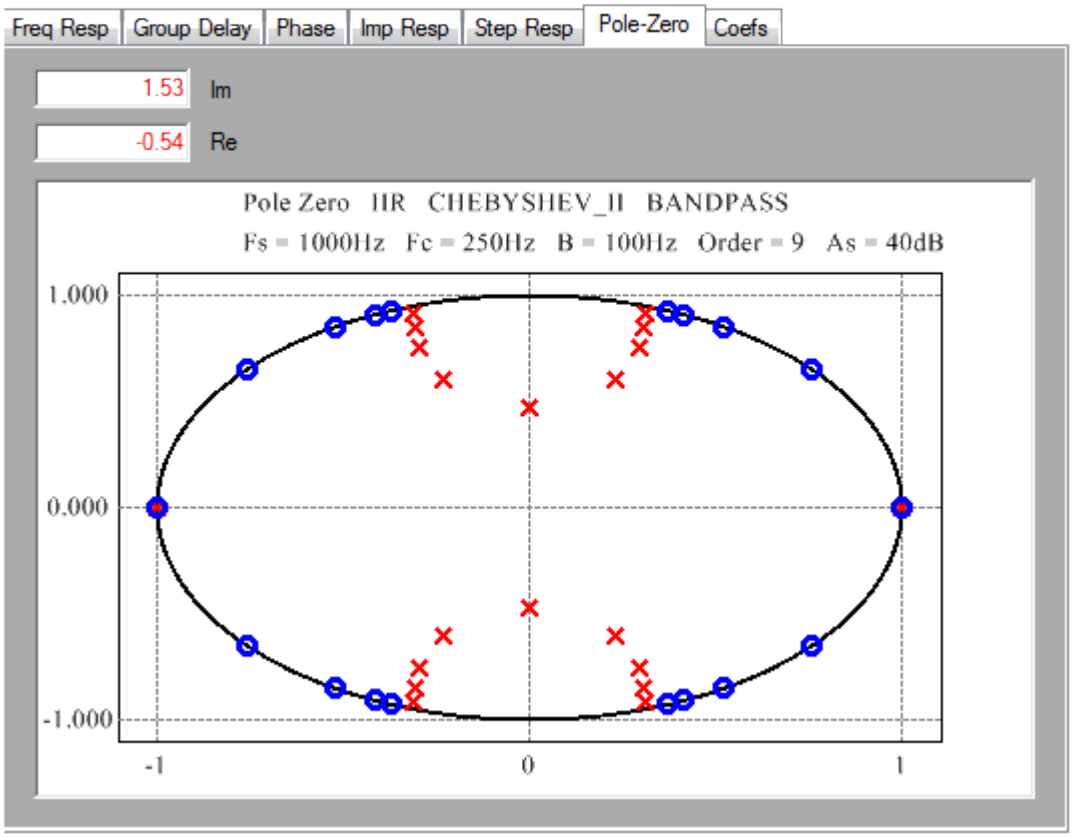

Fig. 13. Pole – zero graph

By moving the cursor above the graph the program displays both Real and Imaginary part according to the cursor position.
A Copy menu pops up by right-clicking on the graph. By left-Clicking on the Copy the picture will be copied to clipboard. Afterwards the picture (graph) can be copied into our document.

In case of FIR filters the pole zero computation is limited. The program computes poles and zeros if Tap is less than 300. Above this value the necessary computation time would be rather long, on the other hand the crowded graph could not show new information.
There is no such kind of limitation in case of IIR filters.

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3.7/ Coefs

Filter coefficients. Coefficients can be displayed in two forms: Numbers, and Numbers and Headers form. In the latter case different helpful informations are displayed besides the coefficients, such as meaning of coefficients, form of the polynomials, array indexes, etc.
The text displayed in text boxes can be copied even into source code as well.
In case of FIR filters there are no coefficients in the denominator box, because this filter type has no feedback.

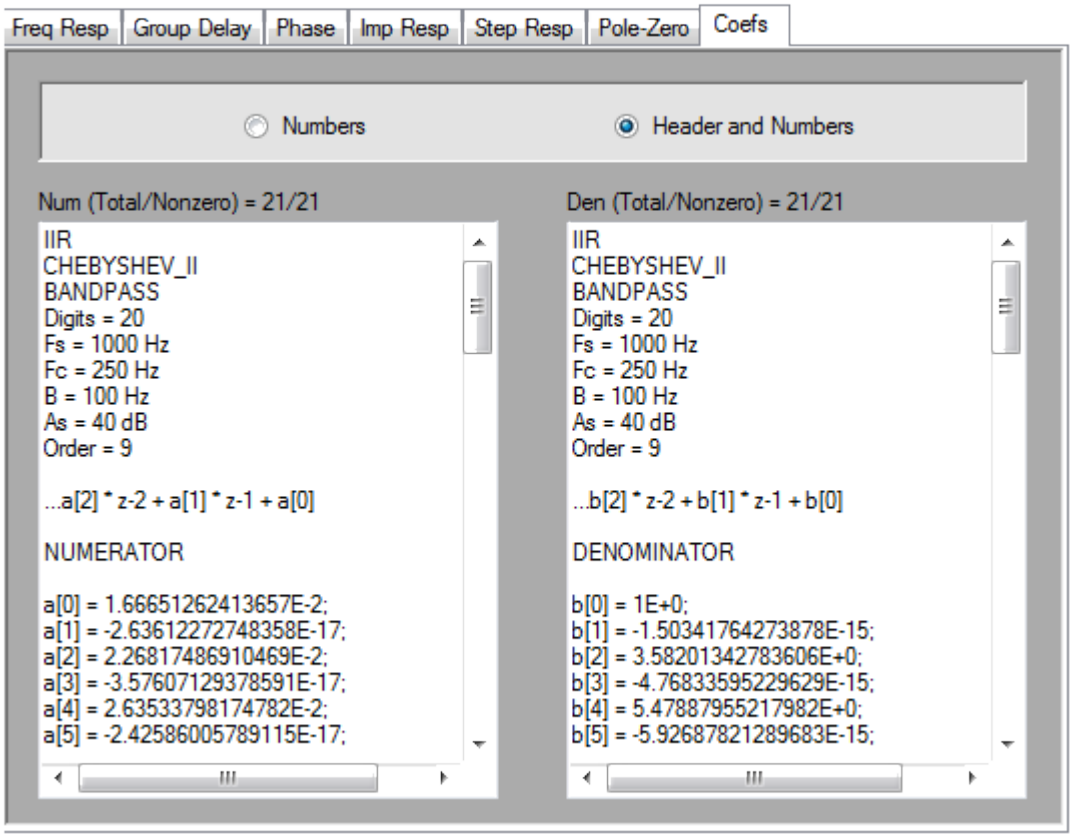

Fig. 14. Filter coefficients window

In case of IIR filters the program displays both numerator and denominator coefficients in two forms. First form contains the original polynomial form. Second form is the Cascade form. Latter form is very helpful especially at high order number and small relative bandwidth. In this case the operation of the IIR filter can become very uncertain, so it is recommended that IIR filters are realized in cascade form.

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4./ Menus

4.1/ File menu

File menu gives opportunity to the user to save file properties into file, or load filter to check the filter graphs. Using load filter menu the program sets all the displayed value according the loaded filters parameters. The **FIR IIR Filter Design** uses “flt” file extension.
The Save Filter As WaveletBasis function is the same as Save Filter, except for the different file extension “wbs”.

File menu gives opportunity to save graph into file in “csv” format.

4.2/ Print

By clicking on the Print menu, the program prints all the filter graphs and the coefficients displayed in Coefs window.

4.3/ User Manual

By clicking on the UserManual/English menu, the program runs Acrobat Reader to display this UserManual in pdf.

5./ FIR filter design

5.1./ Window method

FIR IIR Filter Design supports window based FIR filter design with six methods. Detailed description can be found about the operation of all these methods on the internet, in many related books and studies. As these design methods are standards, and **FIR IIR Filter Design** uses these standard design formulas, therefore this User Manual does not contain repeated description about them.
The only thing we have to mention that the design program computes Bessel interpolation polynomial from 25 terms at Kaiser method.

The first step at filter design is to determine the type of the filter (LP, HP, BP, BS). Then set the desired Fs sample rate, the Fc corner frequency at LP and HP filters, or center frequency and bandwidth (B) at BP and BS.
When using the Kaiser method we can set the desired Alfa constant. If Alfa = 0, the Kaiser window will be equivalent to the Rectangular window.

After or during setting the parameters, Filter Design computes and updates filter coefficients and

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filter graphs.
Number of Taps can be changed in the range of 2 – 9999. At BS band type filters, only odd coefficient numbers are allowed.

Filters are optimized if Optimize checkbox is checked. It means that the filter coefficients are modified by the program in such a way that the following conditions shall be fulfilled:

- LP: sum of coefficients = 1 at 0 Hz
- HP: sum of coefficients = 1 at Fs / 2
- HP: sum of coefficients = 0 at 0 Hz
- BP: sum of coefficients = 1 at Fc
- BS: sum of coefficients = 1 at Fs / 2

At LP and HP filters the magnitude of the frequency response is 0.5 at Fc.
Filter coefficients are displayed in the Coefs window. Coefficients are symmetrical to N / 2. (N = number of coefficients.)

5.2/ Optimal filter design with ParksMcClellan algorithm

This algorithm is running under the name of Remez in the Filter Design program. There are two methods of filter design.

In one case, LP, HP, BP, BS type filters can be designed based on Fs, Fc, B, and Taps parameters as well as RelTransB (relative transmit bandwidth) and PB:SB Weight (Passband – Stopband weight).

Another case, when Combined filter type is chosen. In this case the program designs the filter based on Fs, Taps and the specified parameters in the Desired Parameters table. Number of 2 – 10 bands can be specified in the table.

PB:SB Weight can be changed in the range of 1..10.

6./ IIR filter design

FIR IIR Filter Design supports four method to design IIR filters:

- Bessel type minimal phase
- Butterworth type maximal flat
- Chebyshev I type – scaled to pass band ripple
- Chebyshev II (inverse Chebyshev) – scaled to stop band attenuation

The first step at filter design is to determine the type of the filter (LP, HP, BP, BS). Then set the desired Fs sample rate, the Fc corner frequency at LP and HP filters, or center frequency and bandwidth (B) at BP and BS.
Set the desired Ap or As value at Chebyshev I and II.

The filter order can be set in the range of 1 – 20 at every method. Bessel and Butterworth filters are

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optimized to 3dB (Fc means the 3 dB point), while Chebyshev I and II are not optimized to the 3 dB point (standard definition is kept).

After or during setting the parameters, Filter Design computes and updates filter coefficients and filter graphs.

IIR filters can be sensitive to the value of coefficients, especially with a high order number and a small relative bandwidth because of the feedback. Under the mentioned conditions the operation of IIR filters can become very uncertain, that is why **FIR IIR Filter Design** divides filter coefficients into stages. It is recommended to realize IIR filters in stages.
The effect of the numeric word length can be studied by changing Digits factor.

7./ Licence

The **FIR IIR Filter Design** module operates with two licences. One of them is the *Trial version*, the other is the *Licenced version*. In *Trial version* the module operates without time period limit, but with limited functions:

Limitations:

- Displaying filter coefficients in *Coefs* window is disabled
- Using *UserDefCoef* is disabled
- *File/Save* functions are disabled
- *File/Load* function is enabled only for demo files
- *Trial version* text is displayed in graphs

8./ Meaning of abbreviations and parameters

LP	Low Pass
HP	High Pass
BP	Band Pass
BS	Band Stop
Fs	Sample rate
Ts	Sample time
Fc	Corner frequency. At FIR LP and HP filters the amplitude response is 0.5 at this frequency. At BP and BP filters it means center frequency.
B	Bandwidth at BP and BS filters.

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Taps	Number of coefficients at FIR filters.
Order	Order of filter at IIR filter.
Alfa	The value of Kaiser constant at Kaiser filters
Ap	Pass band ripple at IIR Chebyshev I filters in dB
As	Value of minimal attenuation at IIR Chebyshev II filters in dB
FreqUnit	Frequency unit

uHz	=	microHertz
mHz	=	milliHertz
Hz	=	Hertz
kHz	=	kiloHertz
MHz	=	megaHertz
GHz	=	gigaHertz

FFT	Fast Fourier transform
MRA	Multiresolution analysis
AMD	Amplitude distortion
PHD	Phase distortion
ALD	Alias distortion

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